NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-377

A Preliminary Quarantine Analysis of a Possible Mariner Venus 1972 Mission

C. W. Craven
E. J. Sherry
J. A. Stern

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

April 15, 1968

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Memorandum 33-377

A Preliminary Quarantine Analysis of a Possible Mariner Venus 1972 Mission

C. W. Craven
E. J. Sherry
J. A. Stern

Approved by:

W. S. Shipley, *Manager*
Environmental Requirements Section

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

April 15, 1968

TECHNICAL MEMORANDUM 33-377

Prepared Under Contract No. NAS 7-100
National Aeronautics & Space Administration

Contents

Table

Figures

Abstract

A preliminary quarantine analysis of a possible *Mariner* Venus 1972 mission has been carried out to identify technical areas requiring further investigations or actions. Quarantine constraints for the analysis were derived from prior constraints established for earlier planetary missions. A quarantine allocation model was developed that permits easy test of the probability of contamination from key sources. Concern was mainly directed to the lander capsule, spacecraft, biobarrier, and various debris as possible sources of contamination. Various mission modes considered included separation or no separation of the planetary vehicle, separation and bias aiming of the spacecraft to avoid impact, and separation but crashing spacecraft. Areas for further investigation have been identified.

A Preliminary Quarantine Analysis of a Possible *Mariner* Venus 1972 Mission

I. Introduction

It is important for mission success to include detailed quarantine consideration during early baseline studies. Although quarantine criteria have not yet been established for a possible *Mariner* Venus 1972 mission which will perform atmospheric and surface experiments, it is feasible to derive constraints suitable for planning purposes from the constraints and criteria previously established for other planetary missions. These criteria are documented for the following missions:

(1) *Mariner* Mars 1964. A Mars flyby mission — *Mariner IV* (Ref. 1).

(2) *Mariner* Venus 67. A Venus flyby mission — *Mariner V*.[1]

(3) *Mariner* Mars 1969. A Mars mission with two flyby spacecraft.[2]

(4) *Voyager* Mars 1973. A Mars mission with two orbiting spacecraft and two lander capsules (Ref. 2).

This report, therefore, discusses the contamination constraints for these *Mariner* and *Voyager* missions and presents the model used in deriving them. It then identifies some general modes of contamination due to the *Mariner* 1972 mission. A contamination model is developed in Eqs. (1) and (2) and the notation used is carried over into Figs. 1–5. The numerical allocations and comments on the example presented in the figures are followed by the motivating philosophy of the capsule sterilization plan. From this preliminary quarantine analysis, a few recommendations are made for future work.

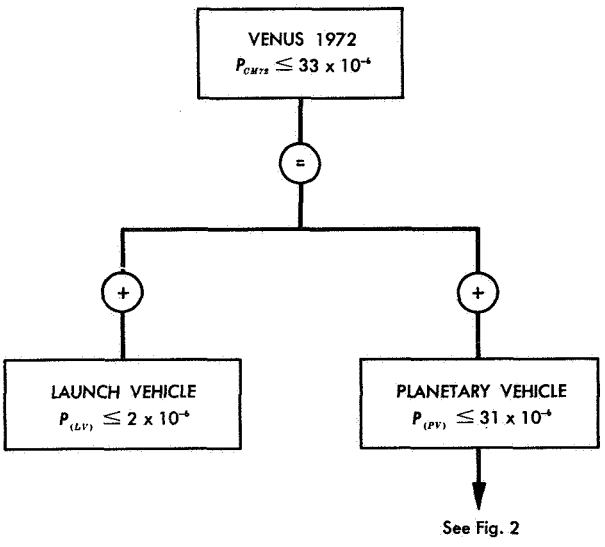

Fig. 1. Probability of planetary contamination allocations, *Mariner* Venus 1972

[1]Haynes, N. R., "*Mariner* Venus 67, Prelaunch Analysis of Contamination Probability." *Project Document 123*, Jet Propulsion Laboratory, May 1, 1967.

[2]Letter from N. W. Cunningham, NASA Headquarters, to H. M. Schurmeier, JPL, "Biological Quarantine Criteria for *Mariner* Mars 1969," Dec. 5, 1966.

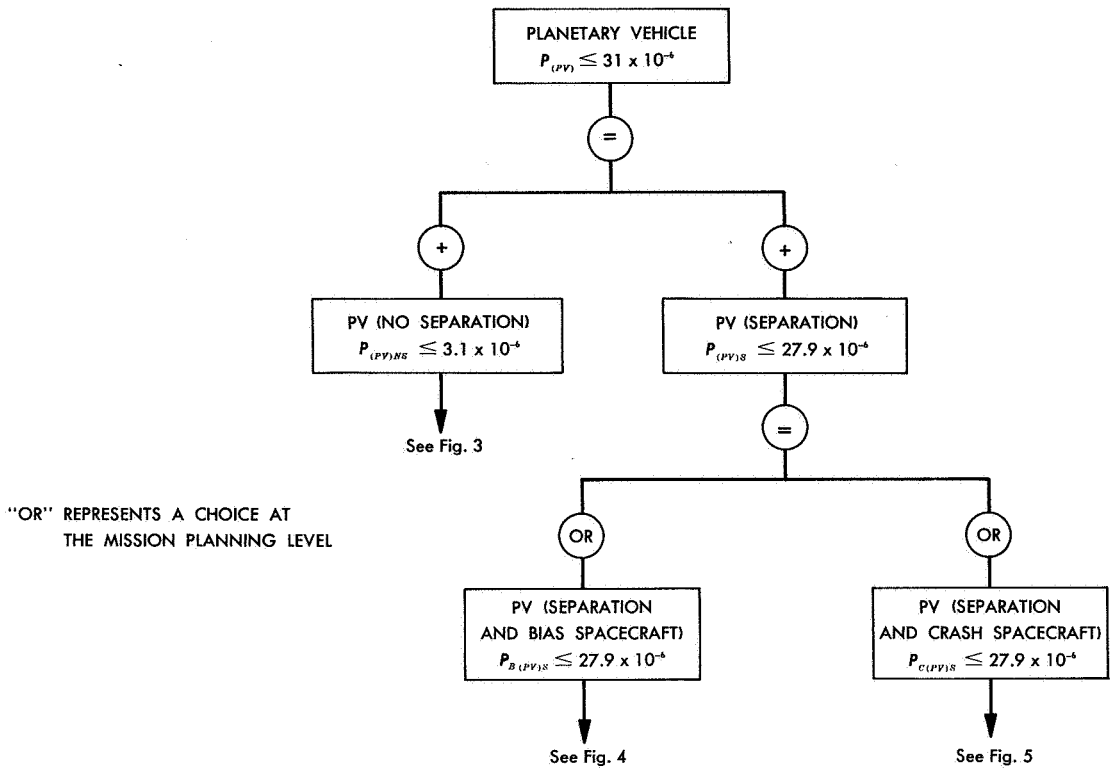

Fig. 2. Probability of contamination from the planetary vehicle given a no separation, a separation with spacecraft bias, or a separation with spacecraft crash mission possibilities

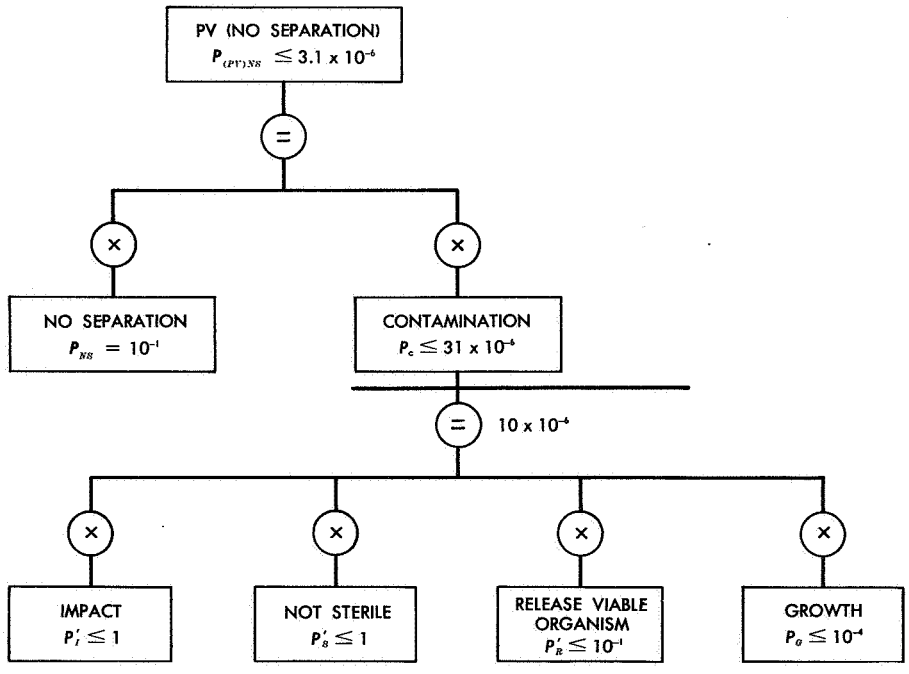

Fig. 3. Planetary vehicle probability of contamination, no separation

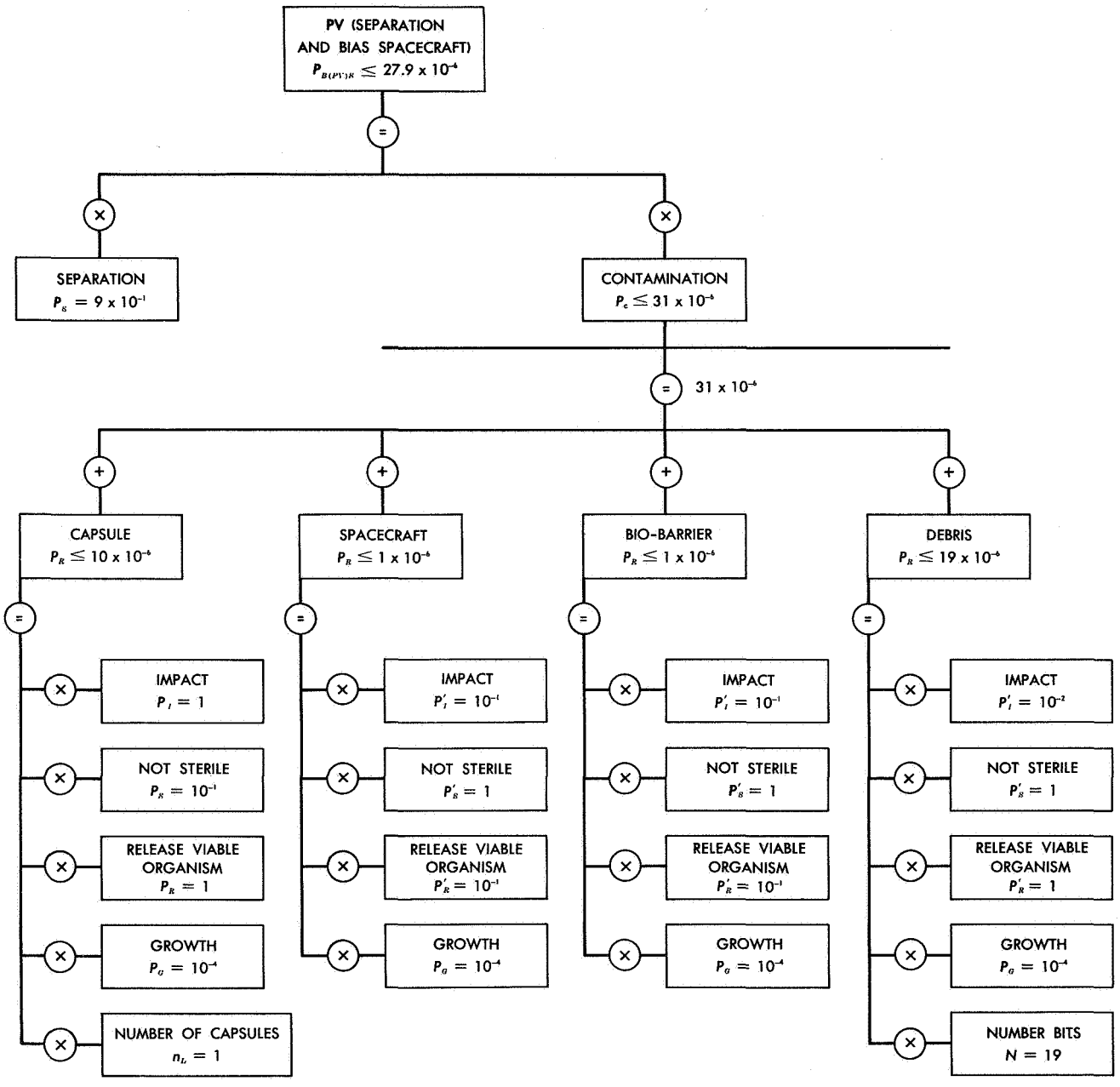

Fig. 4. Planetary vehicle probability of contamination, separation

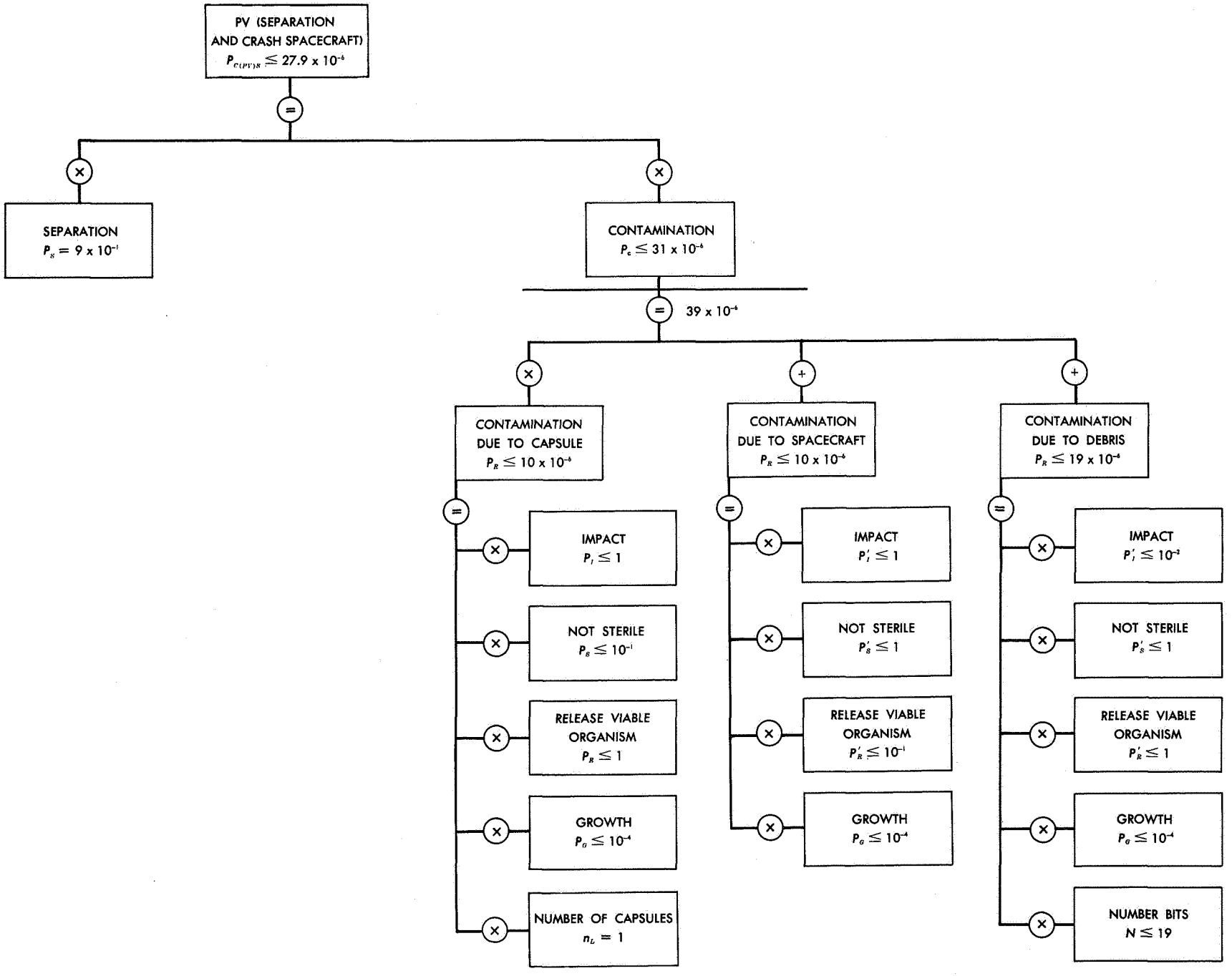

Fig. 5. Planetary vehicle probability of contamination, separation–crash spacecraft

II. Quarantine Criteria

The *Mariner* Mars 1964 mission was constrained to a probability of contamination no greater than 3×10^{-5}. This included contamination of Mars by viable organisms from the intact spacecraft, its ejecta, and associated launch vehicle. The *Mariner* Venus 67 mission was similarly constrained to a probability of contamination no greater than 3×10^{-5}, while the *Mariner* Mars 1969 mission is constrained to a probability of contamination no greater than 6×10^{-5} for two flights. The *Voyager* Mars 1973 mission, as planned, was somewhat more complex in that two capsules and two spacecraft were to be launched on a single launch vehicle. Each capsule was to be designed for deorbit and landing on the Mars surface while each spacecraft was to be designed for long term orbit about Mars. Constraints for this mission were as follows:

(1) Probability of contamination due to each sterilized capsule, no greater than 1×10^{-6} (for two capsules: 2×10^{-6}).

(2) Probability of contamination due to each spacecraft and its ejecta, no greater than 3×10^{-5} (for two spacecraft: 6×10^{-5}).

(3) For unsterilized items common to both spacecraft such as launch vehicle stages and adapters, probability of contamination to be included in the probability allocation for the two spacecraft.

Summation of the above values shows that the total allowable probability of contamination for the *Voyager* Mars 1973 mission amounted to 62×10^{-6}. This value, higher than those for *Mariner* Mars 1964 and *Mariner* Mars 1969, took into account the increase in major hardware items (two lander capsules and two orbiting spacecraft).

In establishing the above constraints, it was necessary for the National Aeronautics and Space Administration (NASA) to satisfy an overall planetary constraint ensuring a low probability of contamination of a particular planet of interest during the period of biological exploration. This overall probability of contamination of a planet (Mercury, Venus, Mars, Jupiter) has been limited to 1×10^{-3} (Ref. 3). In deriving specified constraints for individual planetary missions, consideration was given to possible total numbers of lander capsules and flyby or orbiting spacecraft during the period of biological exploration 1967–1990 (Ref. 4).

Translating the criterion to the probability of contamination per mission, P_{CM}, requires the establishment of an upper bound for the number of planetary missions, n_M, to be flown. If one takes into account the number of launch opportunities and the present budgetary constraints, 30 missions does not seem unreasonable.[3] Thus the policy directive can be applied to a single mission by the following equation:

$$10^{-3} \geq 1 - (1 - P_{CM})^{n_M} \geq n_M P_{CM} \left[1 - \frac{(n_M - 1)}{2} P_{CM} \right] \quad (1)$$

Substituting the value 30 for n_M, one finds that if the probability of contamination per mission, P_{CM}, is kept less than or equal to 3.3×10^{-5}, the NASA Policy Directive (Ref. 3) is satisfied. Thus in the following analysis for a *Mariner* Venus 1972 mission, the probability of contamination for the mission, P_{CM72}, will be taken as less than or equal to 3.3×10^{-5}. The value for P_{CM} agrees with the value used for the *Mariner* series. It appears, however, to conflict with $P_{CM} \leq 6.2 \times 10^{-5}$ for the *Voyager* Mars 1973 mission, but it agrees if one takes into account that the *Voyager* Mars 1973 mission is, in reality, two missions using one launch vehicle.

III. Modes of Contamination

For the purpose of this analysis, it has been assumed that the Venus 1972 mission flight hardware will comprise a two-stage *Atlas/Centaur* launch vehicle and a planetary vehicle (spacecraft and sterilized lander capsule). It is difficult to identify in detail the various modes of contamination before the preliminary hardware is designed. Nevertheless, general modes of contamination must be listed to develop a quarantine model for use in the analysis. An abbreviated quarantine model is shown in Figs. 1–5. The principal potential sources of contamination are

(1) Launch vehicle.

(2) Planetary vehicle (intact planetary vehicle, spacecraft, capsule, bio-barrier, and debris).

[3]Private communication from L. B. Hall to J. A. Stern, JPL, "Number of Missions to Venus," Oct. 13, 1967.

IV. Quarantine Equation

A quarantine equation suitable for use with any planetary mission has been developed and reviewed in considerable detail (Ref. 5). This equation was used for the *Mariner* Venus 67 Prelaunch Analysis of Contamination Probability[1]. A form of this equation is:

$$P_{CM72} = P_{(PV)} + P_{(LV)} \tag{2}$$

where

$P_{(PV)}$ = probability of planetary contamination due to the planetary vehicle (PV), and

$P_{(LV)}$ = probability of planetary contamination due to the launch vehicle (LV).

The probability of planetary contamination due to the planetary vehicle (isolated from Eq. 1) can be expanded and expressed by the following equation:

$$\begin{aligned} P_{(PV)} &= P + P' \\ &= n_L (P_I P_S P_R P_G) + \sum_i (P'_I P'_S P'_R P_G)_i \end{aligned} \tag{3}$$

where

P = probability of contamination due to the lander(s)

P' = probability of contamination due to sources other than the lander(s) (the form of this expression depends on the particular mission profile)

n_L = number of landers per mission

P_I = probability of a lander impacting the planet

P_S = probability of at least one viable microorganism on a lander as it impacts the planet

P_R = probability of an organism on a lander which has undergone a terminal sterilization cycle (TSC) being released onto the planetary surface

P_G = probability of a released organism growing on the planetary surface and biasing future experiments

$\sum_i$ = summation taken over the i sources of possible nonlander contamination, such as the booster, spacecraft, bio-barrier, spacecraft ejecta, etc.

P'_I = probability of impact of one of these sources

P'_S = probability of at least one viable microorganism on one of these sources upon impact

P'_R = probability of a viable organism from the impacting item being released onto the surface of the planet or into its atmosphere.

The factors of growth and release must be defined before the above equation can be used. For this mission, these are as follows:

(1) The probability of growth for this study was taken as 1×10^{-4}. This is a lower value than that specified for use with other missions but was considered valid at the time this study was performed,[4] which was prior to the *Mariner V* and Soviet *Venera 4* missions.

(2) The probability of release of a viable organism from a lander capsule is taken as near unity. (However, this high probability of a viable organism being released from a sterilized capsule is equivalent to the probability of the capsule being contaminated and is, thus, a very conservative value.)

(3) The probability of release of a viable organism from an unsterilized spacecraft, launch vehicle, and debris is equivalent to the probability of the object being contaminated at time of impact. For purposes of this analysis, the probability of release is considered to be near unity except for the spacecraft and bio-barrier which see high entry temperatures. (Again, since this is conditioned on the probability of spacecraft, launch vehicle, or debris impact, it is conservative, too.)

V. Numerical Allocations

The assumed allowable probability of contamination for the possible *Mariner* Venus 1972 mission (33×10^{-6}) has been sub-allocated as follows:

(1) Launch vehicle, 2×10^{-6}.

(2) Planetary vehicle, 31×10^{-6} (Fig. 1).

The low value assigned to that launch vehicle can be met by following a predetermined guidance policy that provides for aimpoint biasing. Previous operational experiences with *Mariner* Mars 1964 and *Mariner* Venus 67

[4]Private communication from L. B. Hall to J. A. Stern, JPL, "Value of Probability of Growth, P_G, for Venus," Sept. 29, 1967.

have proved the adequacy of the biasing technique. The relatively higher value allocated to the planetary vehicle has been chosen to allow for possible accidental impact of the intact planetary vehicle in case of no separation and for possible accidental impact of the spacecraft, capsule, bio-barrier, and debris in case of separation. The various routes of possible contamination with allocated numerical values are shown in Figs. 1–5.

VI. Probability of Contamination Calculations

Preliminary calculations of the probability of contamination have been carried out to determine whether the contamination allocations can be met. The calculations have been made for various expected sources in the general order outlined in Figs. 1–5. Symbols used in the figures indicate dependent and independent events and operations of addition and multiplication. Although the numerical values were selected for planning purposes only, they are generally realistic and probably can be used for a later and more exact analysis.

The first calculation takes into account the possibility that the spacecraft and the capsule do not separate. As can be seen in Fig. 3, the contamination probability of 10×10^{-6} for this event is well within the allotted limit of 31×10^{-6}.

It has been found (Fig. 4) that the allocation for the planetary vehicle, 31×10^{-6}, can be met for the case of a deflected spacecraft and a single capsule that is decelerated before entry if the following requirements are satisfied:

(1) The probability of non-separation of the planetary vehicle does not exceed 10^{-1}.

(2) The probability of release of a viable organism from parts of a planetary vehicle after high speed entry and burn-up does not exceed 10^{-1}.

(3) The probability of impact of the spacecraft does not exceed 10^{-1}.

(4) The capsule is sterilized so that the probability of non-sterility does not exceed 10^{-1}.

(5) The probability of impact of the bio-barrier does not exceed 10^{-1}.

(6) The probability of impact of debris from the planetary vehicle (assuming 19 items) does not exceed 10^{-2}.

An alternate case of a single capsule and crashing spacecraft requires a different treatment since the bio-barrier would probably be retained as a part of the spacecraft and not merit separate consideration. It is clear from Fig. 5 that the contamination probability (39×10^{-6}) of this event is greater than the allocated limit of 31×10^{-6}.

It may be possible that the quarantine allocation for this mode could be met without a deflection maneuver if adequate recognition were given in the analysis to the heating that the spacecraft will undergo at time of planetary entry. A previous analysis[1] suggests that the entry of teflon bodies (3×10^{-4} – 0.57-in. diam) at 35,000 ft/s will result in sufficient heating to cause sterility. If the mission profile requires high entry angles (greater than 45°), and high entry velocities (36,000 ft/s), and if the spacecraft is composed of different materials (magnesium–3%, texolite–9%, 6061 aluminum–30%, fused silica–9%, 2074 aluminum–46%, and stainless steel–3% [Ref. 6]), it is probable that heating and break-up at entry will lead to complete surface sterilization. Since the heated particles will also undergo considerable surface melting and glazing, the possibility of release of viable organisms after impact will be greatly reduced. If a value of 10^{-1} can be justified for the probability of release after such high speed entry, the spacecraft crash mode might be utilized.

VII. Capsule Sterilization Considerations

A Capsule Sterilization Plan that is based on constraints established by a Planetary Quarantine Plan and Analysis will delineate all requirements of the sterilization activities and the post-sterilization operations. A detailed Capsule Sterilization Plan has not been prepared for the *Mariner* Venus 1972 mission, but sterilization philosophy and general constraints have been formulated:

(1) The basic method of achieving sterility or the desired probability of a single survivor is dry heat. This is the only method recognized by NASA.

(2) The sterilization process is based on a microbial load estimate. It is expected that contamination will have to be controlled in order to estimate microbial load. Calculations of the sterilization process also require the thermal model of the capsule and the death rates of organisms on different areas at all temperatures above 80°C. The minimum cycle necessary to certify that P_s has been achieved should be used.

(3) No sterile insertion or repair will be permitted. No method has been proved; and development of confidence for these techniques comparable with that for dry heat sterilization appears difficult.

The determination of the actual sterilization process requires a finalization of P_S in Eq. 2. To see how this varies, the relationship between the probabilities of contamination (P and P' from Eq. 2), the probability of impact (P'_I), the probability of a single survivor (P_S) and the increase in equivalent process time[5] (ΔF_T) have been calculated with the values of $P_G = 10^{-4}$ and $P_R = 1$. The results are shown in Table 1.

The trade which remains to be performed in order to properly select P and P' is that between what is gained by science from an increased P' and what penalties are incurred by the resulting increased sterilization time (or vice versa). This requires a detailed system analysis which cannot be performed at this time. However, it does not appear that the penalty of increased sterilization time will be severe: probably a maximum of 3 to 5 hours—only a small percentage of the total process time.

[5] F_{125}. The equivalent sterilizing time at 125°C is that time required to reduce a population of N_0 organisms to a level P_S, assuming instantaneous heat-up and cool-down.

ΔF_{125}. The increase (in minutes) of the equivalent sterilizing time at 125°C necessary to reduce the population of N_0 organisms to a level P_S as P_S decreases from 3.0×10^{-4}.

VIII. Recommendations

Although this quarantine analysis is quite preliminary it does indicate areas that merit further investigation. Action should be taken to

(1) Develop a *Mariner* Venus 1972 guidance policy that provides for aimpoint biasing.

(2) Develop a plan that ensures control of possible launch vehicle and planetary vehicle debris during the design, manufacture, and handling phases.

(3) Initiate a study that will better define the probability of release of a viable organism from an unsterilized planetary vehicle after it has been subjected to heating and burn-up due to high speed entry.

(4) Develop a plan for capsule sterilization that will ensure non-release of a viable organism at a predetermined level, i.e., 10^{-1}.

(5) Carry out the quarantine analysis in greater depth after a *Mariner* Venus 1972 mission is fully defined.

Table 1. Relationship between probabilities of contamination, probabilities of survival, and change in required equivalent sterilization time

P'	$\sum_i (P'_I)_i$	P	P_S	ΔF_{125}	
				$D_{125} = 210$ min	$D_{125} = 20$ min
1.0×10^{-6}	1.0×10^{-2}	3.0×10^{-5}	3.0×10^{-1}	+0 min	+0 min
1.1×10^{-5}	1.1×10^{-1}	2.0×10^{-5}	2.0×10^{-1}	+37 min	+3.5 min
1.6×10^{-5}	1.6×10^{-1}	1.5×10^{-5}	1.5×10^{-1}	+61 min.	+5.8 min
2.0×10^{-5}	2.0×10^{-1}	1.1×10^{-5}	1.1×10^{-1}	+91 min	+8.8 min
3.0×10^{-5}	3.0×10^{-1}	1.0×10^{-6}	1.0×10^{-2}	+308 min	+29.4 min

References

1. Haynes, N. R., and Gordon, H. J., *A Study of the Probability of Depositing Viable Organisms on Mars During the Mariner 1964 Mission.* Technical Memorandum 33-194. Jet Propulsion Laboratory, Pasadena, Calif., Oct. 23, 1964.
2. *Planetary Quarantine Plan, Voyager Project,* NASA OSSA 818-11-PQ001, Third Revision. National Aeronautics and Space Administration, Washington, D.C., June 1, 1967.
3. *Outbound Planetary Biological Contamination Control,* NASA NPD 8020.10. National Aeronautics and Space Administration, Washington, D.C., Sept. 7, 1967.
4. NASA Position Paper, *A Note on COSPAR Resolution 26.5.* National Aeronautics and Space Administration, Washington, D.C., May 1966.
5. Light, J. O., et al., "A Discussion of the Planetary Quarantine Constraints," *Proc. COSPAR,* Vienna, May 1966.
6. Wolfson, R. P., *Planetary Quarantine Study,* Document VOY-CO FR, pp. A-87 and D-11. General Electric Company, Advanced Interplanetary Programs, Pasadena, Calif., July 28, 1967.